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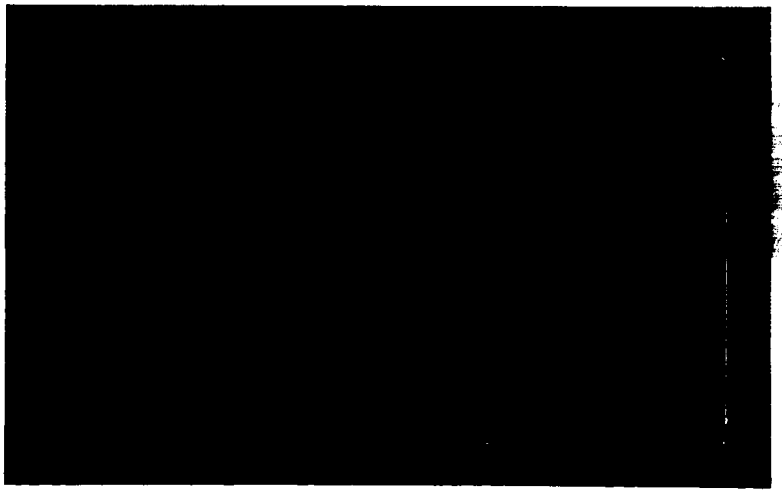

FACILITY FORM 602

(ACCESSION NUMBER)

44

(PAGES)

CR#88995

(NASA CR OR TMX OR AD NUMBER)

(THRU)

(CODE)

(CATEGORY)

I.S.A.V. Memo No. 194

HELICOPTER NOISE

Report for the period

1st December, 1966-30th June, 1967

N.A.S.A. Grant N.G.R.-52-025-002

1st July 1967.

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HELICOPTER NOISE

REPORT FOR 1st DECEMBER, 1966 - 30th JUNE, 1967

RESEARCH SPONSOR: National Aeronautics and Space Administration, Washington D.C.

N.A.S.A. Grant N.G.R.-52-025-002

RESEARCH CONTRACTOR: Institute of Sound and Vibration Research, University of Southampton.

Contract No. 9634/32

RESEARCH PERSONNEL:

Supervisor: Professor E.J. Richards

Research Staff: J.W. Leverton (Research Fellow)

Vacancy

Associate: Professor J.P. Jones

Technical Assistant: R.E. Couser

PREFACE

Professor E.J. Richards, Director of the Institute of Sound and Vibration Research and supervisor of this contract, is leaving at the end of the academic year (31st September, 1967) to become Vice-Chancellor at Loughborough University. The supervision of this work will be taken over by Mr. C.L. Morfey when he returns from America in September 1967.

Professor J.P. Jones will, of course, continue to act as an Associate.

Mr. R.E. Couser (Technical Assistant) is leaving at the end of July 1967. The vacant position is being advertised; until this can be filled it is hoped to employ a vacation student to help with the analysis and test work.

The second research position has not been filled to date. A number of applications have, however, been received and it is likely that a research fellow or assistant will be appointed in the near future.

1. INTRODUCTION

This report summarizes the third six months (1st December, 1966 - 31st May, 1967) of the contract period.

The work during this six months has been concentrated mainly on rotational or discrete frequency noise with the main emphasis on completing the experimental programme and analysing the results.

The Spectral Dynamics system is still not complete due to a six month delay in obtaining the General Radio Level Recorder. This has not limited to any great extent the use of the Spectral Dynamics Analyser since this has been temporarily coupled to a standard B & K Level Recorder. The modification to the G.R. Recorder is now almost complete and should be available in a few weeks.

The tandem rotor investigation has been delayed, in the course of other work under a Ministry of Technology contract. Initially this was due to mechanical difficulties associated with mounting the new gears and later to the lack of manpower.

2. SUMMARY OF EXPERIMENTAL PROGRAMME

The I.S.V.R. programme consists of using rotors fitted with 1, 2, 3 and 4 blades and making noise measurements over as wide a range of conditions as possible. The upper rotor speed is 1000 R.P.M. which with the 9 ft. diameter rotor is equivalent to a tip speed of 475 ft./sec. The lower speed limit is set by the level of the background or general noise in the laboratory: this has been shown from the results obtained to be 300 R.P.M. The tip speed range of the rig is therefore 142 → 475 ft./sec. Pitch settings on the rig have been varied from 0° to 14°, with the upper setting being limited by 'stall' effects. It should be noted that unlike helicopter rotor blades which either have built-in twist or variable chord, the I.S.V.R. model blades are of constant chord with no twist.

In the I.S.V.R. work measuring positions have been in general limited to those shown in Fig. 1, although checks on the effect of distance from the rig and position of the microphone in the room have been carried out.

The main emphasis of the work, as outlined in the two previous reports[1,2], has been on the study of rotational or discrete rotor noise. A limited study of the 'vortex' noise has been made by using overall and dB.A. measurements.

3. ROTATIONAL NOISE

3.1 I.S.V.R. Single Rotor Tests

3.1.1 Progress of experimental programme

Measurements of noise have been taken with the rig fitted with 4, 3 and 2 blades at a distance of 27 ft. (6R.). This position was chosen after tests had been carried out with the microphone position up to 36 ft. from the rig. This work showed that the rotational (harmonic) content of the noise remained practically constant after 20 ft. relatively, although the absolute level decreased with increase in distance.

The 4 and 3 bladed tests were recorded on a standard NAGRA IIIB DIRECT tape recorder using the equipment outlined in reference 1. Because of the very low fundamental frequencies associated with the 2 bladed rotor these recordings have been made on a Leevers-Rich F.M. tape recorder.

The range of conditions at which recordings have been made is given in Appendix 1. The upper limit of 1000 R.R.P.M. was determined by the design capabilities of the rig and 'drive power' available. At higher pitch settings the upper speed limit was set by the level of turbulence or re-circulation of air set in the laboratory by the rig. At the high speed/high pitch settings 'lumps' of turbulence can be heard to hit the blades. This caused the noise level to fluctuate and produce a 'booming' noise. Recordings were not made in this condition, since the main aim is to study the steady state hover regime. The speed at which 're-circulation' affects the rotor can easily be detected, since in addition a sudden change in the noise there is a fluctuation in the power demand on

the drive motor which shows as a speed (R.P.M.) variation on the R.R.P.M. meter.

The narrowband analysis of the 4 and 3 bladed results is complete although the data for the 3 bladed rotor has not been reduced or the traces mounted for reproduction. Since the 2 bladed results have been recorded on an F.M. tape recorder and tape loops are used for the analysis it has been necessary to design and manufacture a control unit which prevents the spurious noise caused by the tape join passing the playback head being analysed with the 'rotor noise' signal. This unit is complete and is being incorporated into the Spectral Dynamics analyser at this present time.

The 1 bladed rotor head has been designed and the head balanced. After some preliminary runs to determine the vibration levels associated with the single bladed rotor head, measurements will be made at the conditions given in Appendix 1.

3.1.2 4 Bladed Rotor Results

For this detailed study of the rotational noise the number of harmonics considered has been limited to 8. The traces presented in this report have, however, been standardised on a frequency basis (i.e. constant trace length) with the result that higher harmonic orders are shown on the traces for the lower R.P.M. conditions. Although only the first 8 harmonic levels are quoted all the harmonic levels that could be detected in the frequency covered (10 → 500 Hz) have been recorded and these are available in the I.S.V.R. files.

The traces reproduced in this report have been chosen to show the effect of altering one condition while keeping the other constant. Figs. 2 and 3 show the variation due to increasing speed at zero pitch and a higher pitch setting (6°). Figures 4 and 5 give traces for the 600 RRPM conditions and show the effect of increasing the pitch from 0° (Fig. 4) to 12° (Fig. 5).

The first 8 harmonic levels, corrected for the fall-off in response of the equipment at low frequencies, are presented in Table 1. These results have been plotted and a selection of the graphs are given in figures 6 to 10.

Because of the large scatter associated with these measurements it is difficult to determine with any accuracy the variation in level with any particular parameter, although they show some definite trends. For example, the increases in level of the harmonics with rotor speed (Figs. 6 - 8) seem to be independent of the pitch setting and approximately the same for all the harmonics considered. In general the rate of increase appears to be in the order of $V^4 \rightarrow V^5$ where V is the velocity of the blade. The variation with pitch (Figs. 9 and 10) seem to be affected by the rotor speed; however, in this case there does not appear to be any simple relationship.

The effect of scatter on the results appears to be large and could be the result of aerodynamic changes on the blades or effects caused by the far from ideal room acoustics. Because of the low frequencies involved it is, however, practically impossible to determine the cause. Many of the results have been checked by re-running tests and in the majority of cases the results have been found to be within $\pm$2dB of the

original result which would be reasonable for this type of work. Attempts are at present being made to reduce these effects by cross-plotting the results and taking the 'best curve'. It is hoped that this will allow the data to be presented in a more useful form.

3.2 Full Scale Tests

3.2.1 Aim of Full Scale Work

The I.S.V.R. programme is, of course, based on the 9 ft. diameter single rotor hover rig which is situated in the semi-reverberant Structures Laboratory. Because of the low tip speed range of the I.S.V.R. single rotor rig as compared to a full scale rotor, and the limitations imposed by operating the rig in an enclosure, it was decided to check that the important parameters and trends being predicted are of a similar nature to those produced by a real helicopter rotor.

Westland Aircraft Ltd., in connection with their M. of A. rotor noise contract, have recently made measurements of the noise produced by a single and two bladed rotor. They have used three different types of blades and measured the noise for a wide range of conditions[3].

Since the present rotor noise investigations are concentrated on rotational (discrete) noise it was decided to use the Spectral Dynamics Analyser fitted with a 2Hz filter for the analysis. Westland Aircraft Ltd. (Yeovil) readily agreed to this work and made available their FM Tape (Loop) Recorder and associated equipment.

3.2.2 Single Bladed Rotor Test

Recordings have been made by Westland of the noise produced by three types of blades - Whirlwind, Belvedere, Sycamore - with both a single and two bladed rotor over a wide range of pitch and R.P.M. conditions. Since the full scale results are being used mainly as a back-up to the I.S.V.R. model tests and in order to reduce the time involved it was decided to limit severely the number of conditions to be analysed.

It was initially intended to select for analysis a representative number of conditions from both the single and two bladed rotor tests. However at the time of analysis tape loops were not available for any of the two bladed results and the analysis had therefore to be limited to the single blade conditions.

The WHIRLWIND results were chosen as the most suitable for analysis, since the Whirlwind blade is the one which represents most closely the WESSEX blade used in the previous full scale 3-bladed tests[4]. By using these earlier results and the recent 1 and 2 bladed results it is planned to study the effect of the number of blades on the harmonic or rotational noise content and compare the results with those obtained from the I.S.V.R. rotor rig.

Although the measurements were made at several positions, the microphone farthest from the whirl tower was considered to be most representative for the study of rotor noise. This microphone is 200 ft. from the $\mathbb{C}$ of the rig, which for the blades used is approximately 8R where R is the rotor radius. Since the I.S.V.R. measurements for rotational noise have been made at either 6R or 8R (from $\mathbb{C}$ of rig) a similar scale exists for the full scale and model tests.

The range of conditions available for the Single Whirlwind Blade Tests are shown in the table below together with those selected for analysis.

1. Whirlwind Blade - (Microphone 200 from ℄ of Tower

RRPM \ PITCH (Cuff)	5°	7°	9°	11°	13°	15°
140	*	+	+	+	+	*
160	*	+	+	+		*
180	*	+	+		+	*
200	*	+	+	+	+	*
230	*	*	*	*	*	*
260	*	+				

* indicates CONDITIONS ANALYSED by ISVR

+ indicates recordings available

The conditions were chosen such that the variation of rotational noise with RRPM (or tip speed) could be determined at minimum pitch (5° Pitch-Cuff) and maximum pitch (15° Pitch-Cuff) settings; and the variation with pitch could be studied at the rotor speed which corresponds most closely to that used on Whirlwind and Wessex helicopters (i.e. 230 RRPM).

Narrow band analysis was performed on the conditions indicated above using the Spectral Dynamics Analyser fitted with a 2 Hz filter. The recordings were made at a tape speed 15 I.P.S., and

played back at 60 I.P.S. so that the fundamental frequency of the lowest speed condition (140 RRPM) was above the lower operating frequency of the analyser which for these tests was 5 Hz. This speed has the additional advantage of effectively decreasing the bandwidth of the filter to 0.5 Hz.

For practical reasons the analysis was restricted to between 5 Hz and 500 Hz, which in terms of 'real' frequencies is 1.25 → 125 Hz. At the maximum rotor speed of 260 R.P.M., this upper frequency is approximately equivalent to the 28th rotational harmonic.

3.2.3 Single Rotor Results

Since these results are being compared to the ISVR tests the detailed study was limited to the first 8 harmonics. The traces presented in Figures 11 and 12 were, however, analysed over a larger frequency range than required with the result that 15 or more harmonics can be detected depending on the rotor speed. The full range of results together with details of analysis, recording and calibration procedures are given in reference 5.

It will be noted that the traces all show 'kicks' or very narrow peaks (lines) superimposed on the rotor noise spectrum. As can be seen these occur at regular intervals and are approximately of the same amplitude over the whole frequency range shown. These 'kicks' result from the spurious noise caused by the tape splice passing over the playback head. Although a control unit was available on the Westland F.M. tape loop machine for 'freezing' the signal etc. while the join was passing the playback head it could not be used with the

I.S.V.R. Spectral Dynamics Analyser.

The levels, suitably corrected for fall-off in equipment response and speed multiplication of the tape recorder on playback, are given in Tables 2 to 4.

These have been plotted in a similar form to earlier results and a selection of graphs is given in Figures 13 to 15.

These results show far less scatter than the model results and definite variations with pitch and rotor speed can be seen.

3.2.4 Propellor Results

The BRITISH HOVERCRAFT CORPORATION LTD. (ISLE OF WIGHT) have made some measurements of the noise produced by their S.R.N.4 hovercraft propellor during ground running. They supplied a copy of their 1.5% narrow band analysis, from which it has been possible to obtain the variations of harmonic levels with tip speed. These results are shown in Figures 16 and 17. Although the results are only available for a particular pitch setting at two speeds the increase in noise with tip speed is very similar to that of the I.S.V.R. rig and full size rotor. The S.R.N.4 propellor is 19 ft. in diameter, with 4 blades having a twist in the order of 53° and an aerofoil section of N.A.C.A. 16 series. These results have been included to show the basic similarity for a wide range of low solidity rotors. The pitch settings quoted on the figure are those at 62.5%R and were made at a distance of 200' from the rig.

3.3 Preliminary Observations on Experimental Results

The results all show that, although there is a slight difference in the rate of fall-off of harmonics with speed, all the harmonics increase with approximately the same power of the velocity, i.e. $V^4 \rightarrow V^5$. This shows clearly that the simple 'Gutin' approach which predicts higher orders for the higher harmonics is not substantiated in practice.

No attempt has been made at the present stage to correlate the results in any greater detail. Even so, these results do tend to confirm that the trends being determined from measurements made on the I.S.V.R. rigs are of a similar nature to those associated with full size helicopter rotors and even highly twisted propellors.

3.4 Theoretical Study

3.4.1 'Gutin' Approach

The 'Gutin' approach outlined in the previous report[2] has been developed by Mr. S.E. Wright to show the effect of changing the various physical parameters of a blade[6]. This has shown that 'solidity', which is not normally considered, is a very important factor in determining the rotational noise level. The indications are that a substantial reduction in rotational noise could be obtained by increasing the solidity. Since, however, helicopter rotors have low solidity this parameter is not very significant. In other applications, such as hovercraft propellors, where high solidity could be tolerated it appears that useful noise reduction could be obtained by fully exploring the apparent advantages of high solidity blades.

Since the simple 'Gutin' solution and experimental results

show large disagreements, this line of investigation has not been developed any further by the author.

3.4.2 Sikorsky Programme

The Sikorsky programme[8] has been adapted for use on the University's I.C.T. 1909 computer and is being tested at the present time. When this testing phase is completed it will be used to predict the noise levels for the ISVR single rotor rig over the range of conditions used for measurements (Appendix 1).

The blade loading which is required in the Sikorsky programme, has been calculated using simple momentum theory. Account of tip losses have been taken into account by using the method outlined by J.P. Rabbott in reference 7.

4. BROADBAND (VORTEX) NOISE

Because of the present emphasis on rotational noise broadband or vortex noise has not been investigated any further than outlined in the previous report[2].

While carrying out the analysis for the rotational noise, dB.A. levels have also been obtained. This weighted overall level has been used for a limited study of the 'subjective' noise produced by the rig. Even though in the previous report it was shown that the traditional vortex noise region contains many discrete components (Section 4 of reference 2) the dB.A. readings can for all practical purposes be considered as a measure of the vortex or broadband noise. The dB.A. levels for the 4 bladed results are given in Table 1 together with the LINEAR overall level (dB. LIN).

5. STALL RIG

The stall rig is now complete and is at present being calibrated. Due to pressure of other work it is not planned to study the effects of stalling the rotor over a discrete area until October 1967.

6. TANDEM ROTOR RIG

The transmission has been rebuilt using nylon gears, and a 10dB noise reduction over the old transmission achieved. This is regarded as satisfactory for rotor noise investigations[6] mentioned in earlier reports.

7. REFERENCES

1. Leverton, J.W. — Helicopter Noise. I.S.A.V. Memo No. 152 N.A.S.A. Report for the period 1st December 1965 - 31st May 1966.

2. Leverton, J.W. — Helicopter Noise. I.S.A.V. Memo No. 167 N.A.S.A. Report for the period 1st June 1966 - 30th November 1966.

3. — Research Work on Turbine Engine Noise Suppression. M. of A. Ref. No. KT/2Z/02/CB.13(b). Brochure F.N.R./8 Westland Aircraft Ltd., March 1965. CONFIDENTIAL.

4. Stuckey, T.J. Goddard, J.O. — Investigation and Prediction of Helicopter Rotor Noise - Part 1, Wessex Whirl Tower Result. J.SOUND VIB. Vol. 5, No. 1, 1967.

5. Leverton, J.W. Couser, R.E. — Helicopter Rotor Noise. Single bladed rotor results. I.S.A.V. Memo No. 169 June, 1967.

6. Wright, S.E. — Helicopter Noise. I.S.A.V. Memo No. 190. Report for the period 1st March - 31st July 1967.

7. Rabbott, J.P. — Static-Thrust Measurements of the Aerodynamic Loading on a Helicopter Rotor Blade. N.A.C.A. Tech. Note No. 3688. July 1956.

8. Schlegel, R.
King, R.
Mill, H.

Helicopter Rotor Noise Generation and Propagation.

USA AVLABS Tech. Report 66-4.

INSTITUTE OF SOUND AND VIBRATION RESEARCH

4-Bladed Tests

TABLE 1

PITCH	RRPM	HARMONIC ORDER								dB LIN	dB.A.
		1	2	3	4	5	6	7	8		
0°	300	$\overline{48}$	$\overline{57}$	$\overline{52}$	$\overline{45}$	$\overline{47}$	$\overline{60}$	48	-	67	60
	400	-	-	-	-	-	-	-	46	69	63.5
	500	-	46½	-	-	48	44	46	48	71	67.5
	600	46	-	49	-	48	48	52	52	75	71.5
	700	52½	-	-	-	49	50	53	54	77	75.5
	800	65½	60	-	49	52	56	56	58	81	79
	900	73	53	-	54	57	58	58	57	85	83
	1000	73	60	56	58	58	59	59	-	87	85.5
2°	300	-	58	52	-	-	57	-	-	69	66.5
	400	53	-	-	-	-	-	-	48	70	66.75
	500	48½	-	-	-	53	44	45	-	70.5	67
	600	53	-	55	-	52	45	48	51	71.5	68.5
	700	58	-	60	-	53	-	53	52	74	71.5
	800	65	59	57	58	58	59	59	56	77	75
	900	73½	63	58	61	66	64	61	56	81	77.5
	1000	71½	70	67	71	66	65	63	67	83	80
4°	300	-	-	52½	-	-	-	48	-	71-72	65.5
	400	67	-	-	57	48	54	46	47	71	65.5
	500	-	62½	59	-	-	$\overline{38}$	37	34	71.5	67.5
	600	59	59	65	59	56	60	57	58	75	70.5
	700	-	-	69	62	62	63	61	63	78.5	74
	800	71	65	67	66	68	68	62	61	81	77
	900	76½	72	68	67	64	69	64	61	84.5	80
	1000	79½	76	72	75	71	71	70	67	88	82

Note: $\overline{48}$ indicates that it is not a clear peak.
- indicates no peak.

cont/d...

PITCH	RRPM	HARMONIC ORDER								dB LIN	dB.A.
		1	2	3	4	5	6	7	8		
6°	300	50	44	43½	-	-	47	-	-	70	66
	400	57	58½	48	57	52	-	46	47	76	66.5
	500	66	63½	62	60	63	65	60	58	75	68.5
	600	-	63	68	65	67	64	62	65	79	72
	700	67½	76	72	65	67	65	68	62	81	76
	800	75½	69	75	70	71	74	71	65	84.5	79
	900	79½	80	74	70	72	73	68	64	87	82.5
8°	300	-	46	42½	45	-	48	45	-	70.5	68
	400	65	43	-	46	44	-	-	-	75	68.5
	500	66	57½	57	55	55	52	53	52	76	70
	600	66	68	73	69	68	61	61	63	79	73.5
	700	68	78½	78	69	68	68	66	65	83	77.5
	800	71	71	68	66	67	68	66	62	86	81.5
10°	300	52	47	47½	47	-	48	-	-	71.5	66
	400	75	-	-	55	56	-	50	50	77-82	68.5
	500	68½	62	-	61	58	60	58	57	77-78	70
	600	68	67	65	66	65	60	60	63	81	73
	700	68	79½	73	64	67	66	64	63	85.5	77
12°	300	53	47	49½	-	-	51	47	-	69	64
	400	75½	54½	53	55	54	53	52	51	77-79	68
	500	74	65½	63	62	60	58	58	57	80	72
	600	65	67	65	67	66	60	63	66	83	75.5
14°	300	57	49½	48½	-	-	49	53	51	70-72	61.5
	400	75	-	62	-	59	-	56	56	79	68.5
	500	73	66	67	67	66	65	62	61	82	76.5

ALL levels are dB rel. 0.0002 DYNES/CM.^{2}

HELICOPTER ROTOR NOISE - HARMONIC NOISE LEVELS

TABLE 2

SINGLE WHIRLWIND BLADE - 230 R.R.P.M.

PITCH (Cuff)	LEVEL - dB - HARMONIC ORDER							
	1	2	3	4	5	6	7	8
5	-	63	61	63	59	60	58	57
7	-	65	62	64	59	60	59	58
9	54	64	63	63	60	59	58	57
11	62	65	67	65	62	61	59	58
13	67	68	69	68	64	63	61	59
15	69	71	72	70	66	64	60	58

TABLE 3

SINGLE WHIRLWIND BLADE - 5° PITCH (CUFF)

R.P.M.	LEVEL - dB - HARMONIC ORDER							
	1	2	3	4	5	6	7	8
140	←			No peaks				→
160	-	50	49	49	43	43	39	41
180	38.5	53	49	53	50	49	46	44
200	49	54	50	53	52	51	43	45
230	-	63	61	63	59	60	58	57
260	57	70	68	68	68	66	65	65

TABLE 4

SINGLE WHIRLWIND BLADE - 13° PITCH (CUFF)

R.R.P.M.	LEVEL - dB - HARMONIC ORDER							
	1	2	3	4	5	6	7	8
140	48	48	43	40	42	42	39	38
160	52	53	51	47	48	42	42	41
180	57	58	54	54	50	47	43	44
200	60	61	59	57	56	52	50	49
230	67	68	69	68	64	63	61	59

APPENDIX 1

I.S.V.R. Single Rotor Test Programme

RRPM \ PITCH °	0	2	4	6	8	10	12	14	
150	*	*	*	*	*	*	*	*	NOT USED FOR ROTATIONAL NOISE STUDY.
200	*	*	*	*	*	*	*	*	
300	*	*	*	*	*	*	*	*	
400	*	*	*	*	*	*	*	*	
500	*	*	*	*	*	*	*	*	
600	*	*	*	*	*	*	*		
700	*	*	*	*	*	*			
800	*	*	*	*	*				
900	*	*	*	*					
1000	*	*	*						

* INDICATES TEST CONDITIONS

ACKNOWLEDGEMENTS

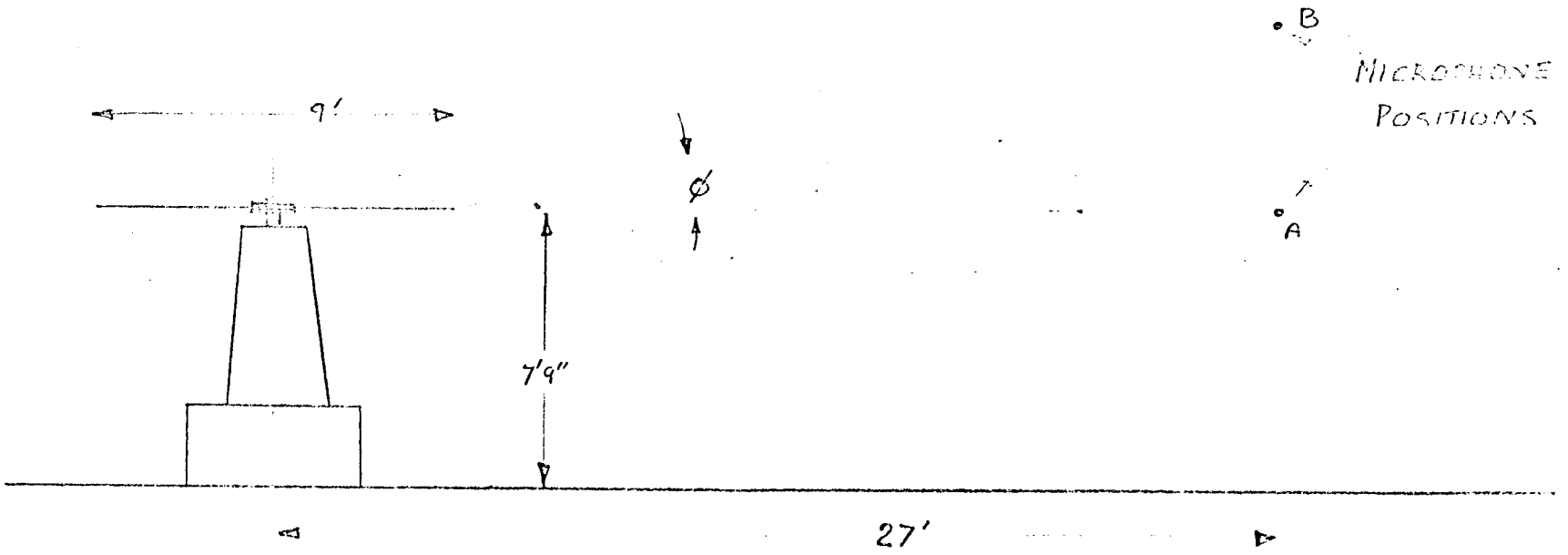
The author would like to thank the following:-

1. Westland Aircraft Ltd., for making available their single bladed Whirlwind measurements and supplying the F.M. tape recorder used in the analysis.

2. British Hovercraft Corporation for supplying results obtained from their recent propellor studies.

NOTE: RIG IS RUN WITH NEGATIVE PITCH.

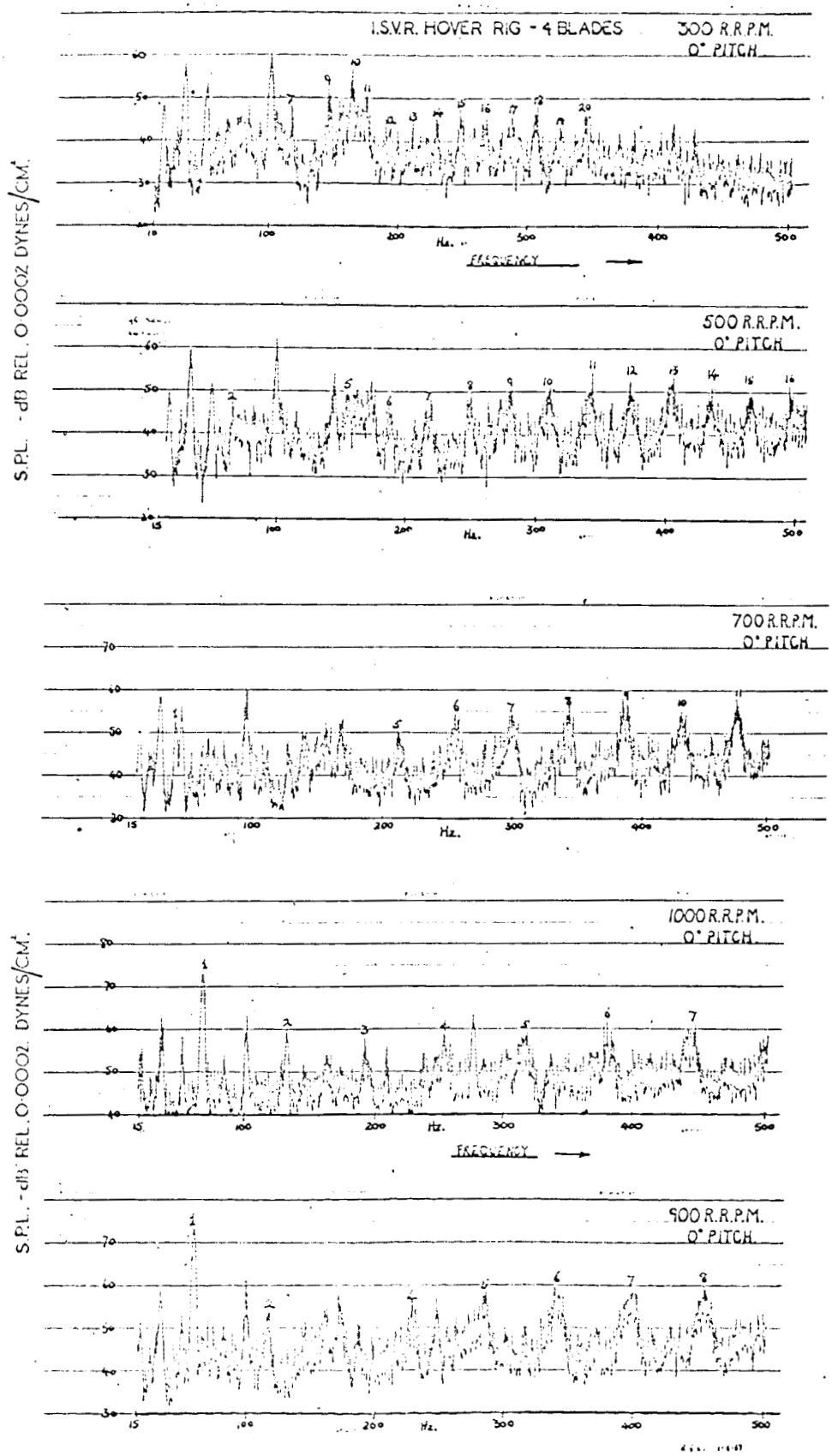
$\phi \simeq 10°$



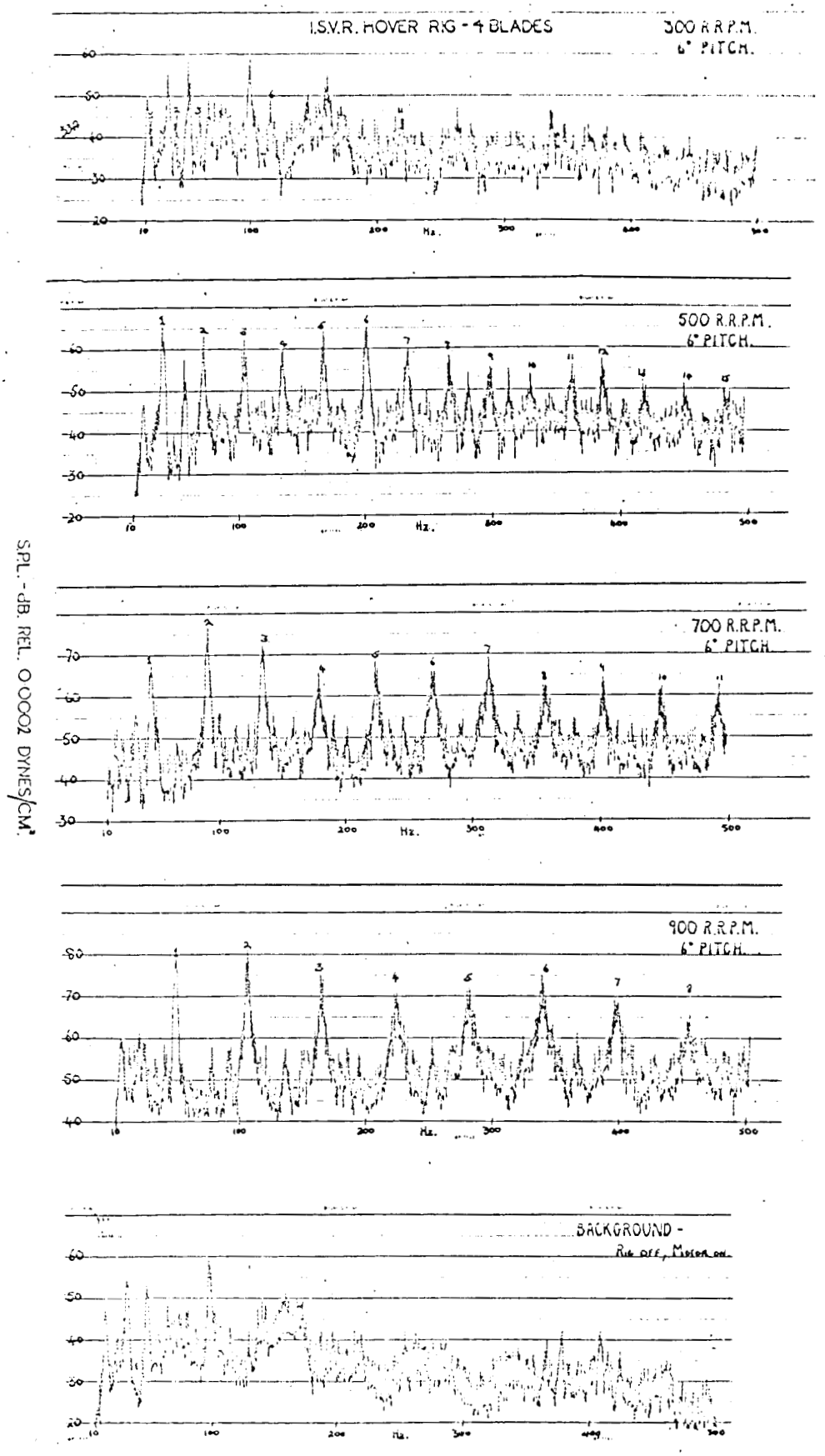
NOT TO SCALE

FIG 1. MICROPHONE LAYOUT - 4 BLADED TESTS

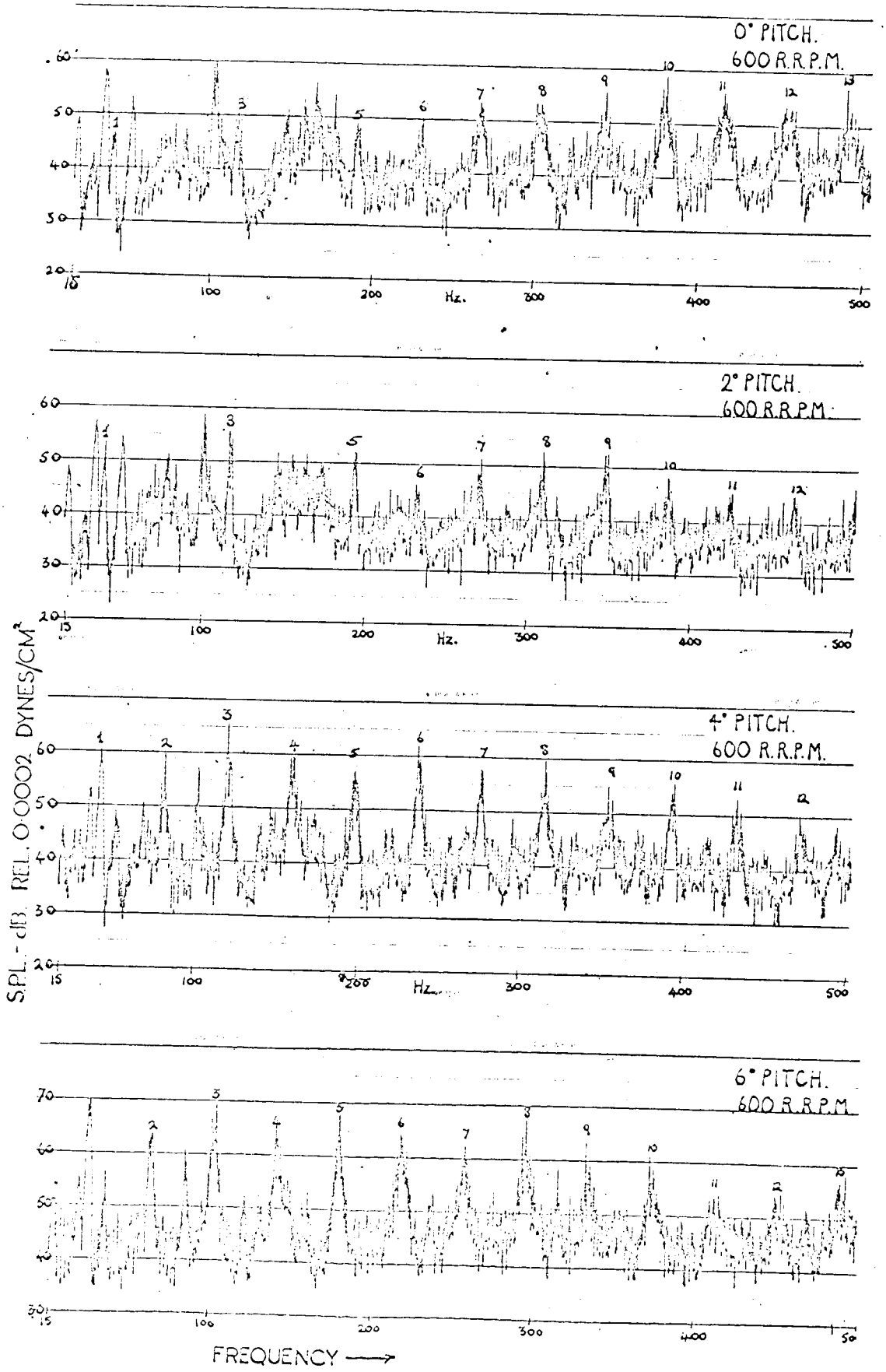
NARROW BAND ANALYSIS OF ROTOR NOISE - 2HZ. B/W. FIG. 2.



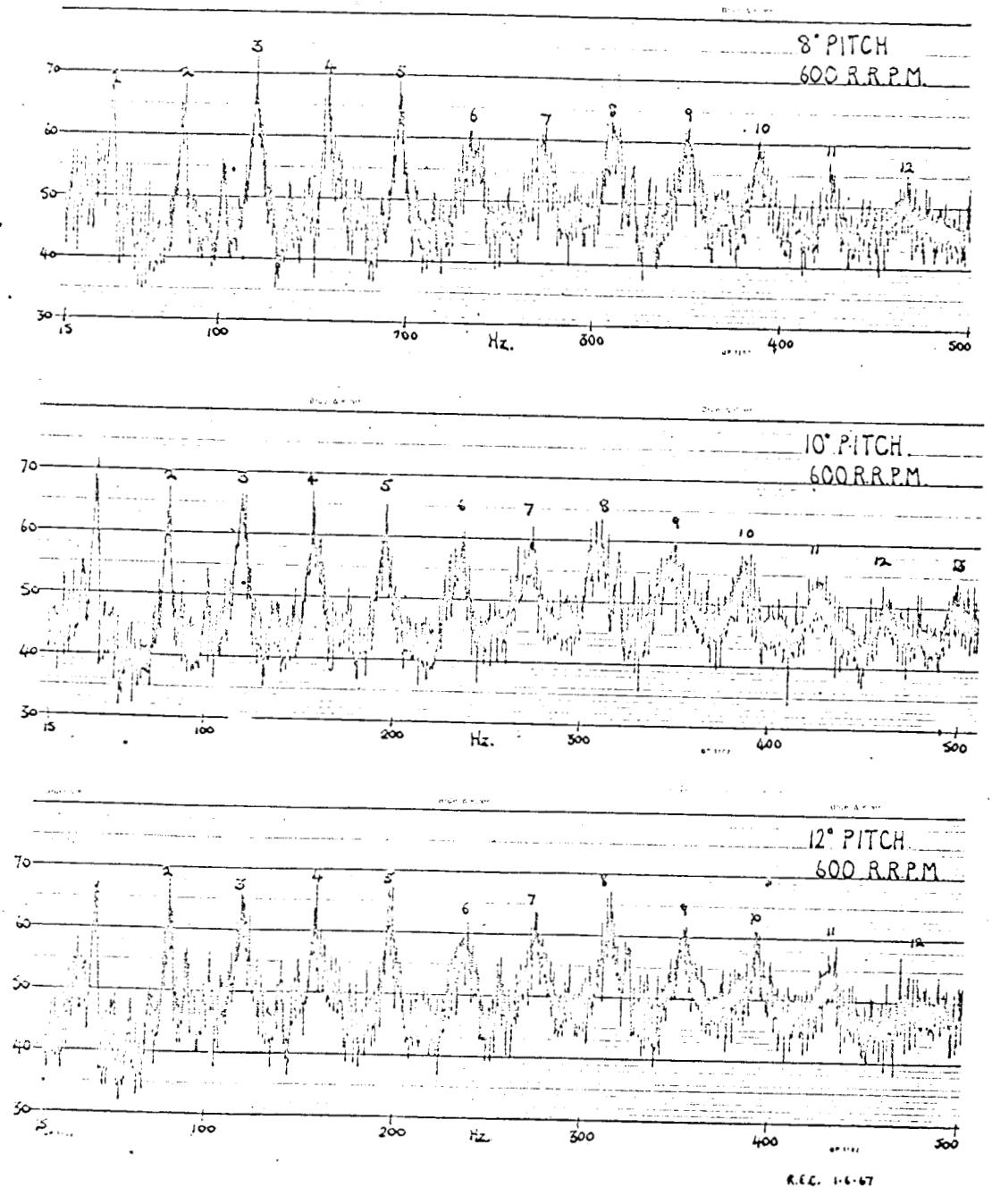
NARROW BAND ANALYSIS OF ROTOR NOISE - 2HZ B/W. FIG. 3.



NARROW BAND ANALYSIS OF ROTOR NOISE – 2 HZ.B/W. FIG. 4.



NARROW BAND ANALYSIS OF ROTOR NOISE - 2HZ.B/W. FIG. 5



I.S.V.R. HOVER RIG - 4 BLADES

VARIATION OF S.P.L. WITH ROTOR R.P.M.

ZERO PITCH

I.S.V.R. 4-BLADED RIG. MICROPHONE 27ft FROM ℄ OF RIG

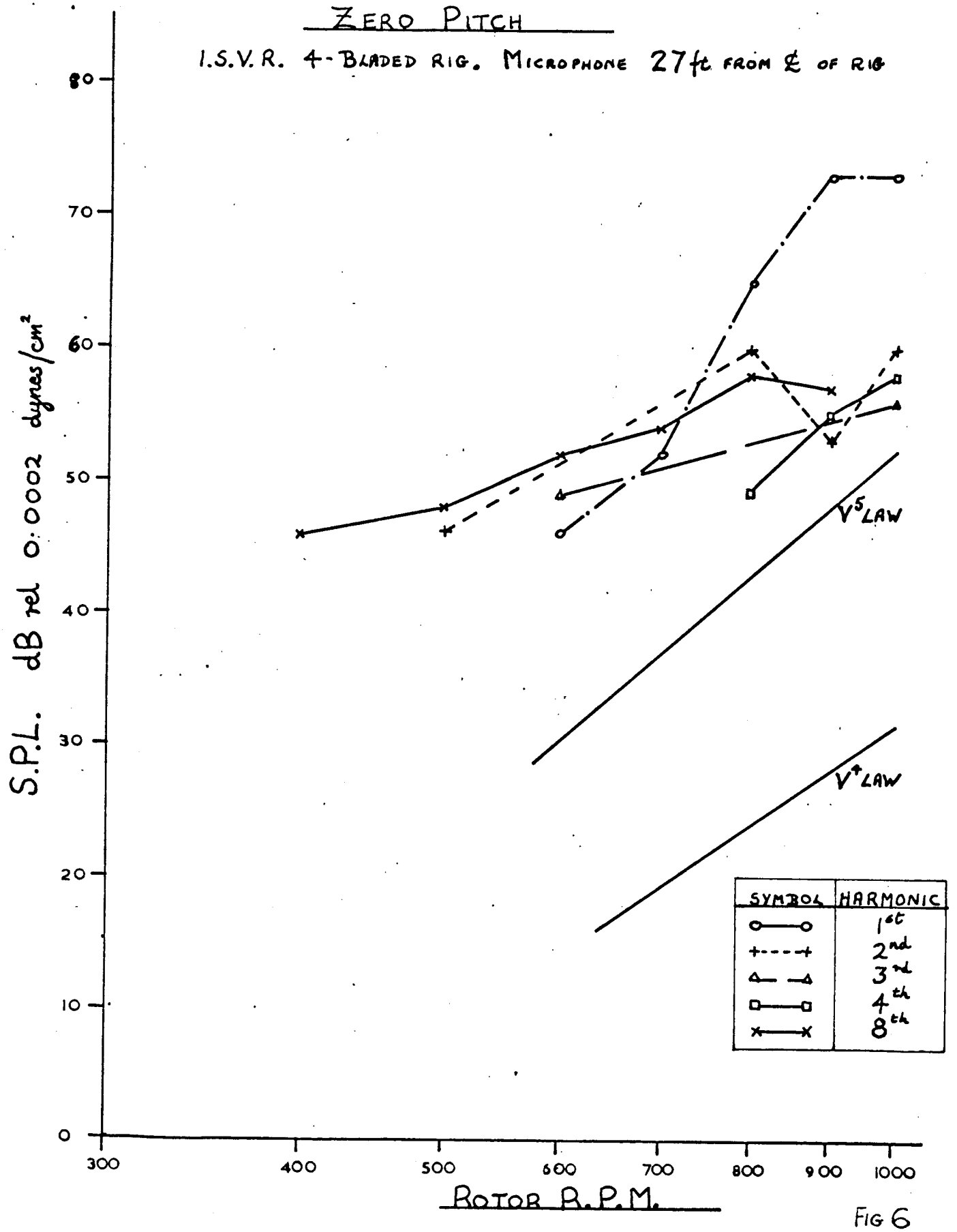
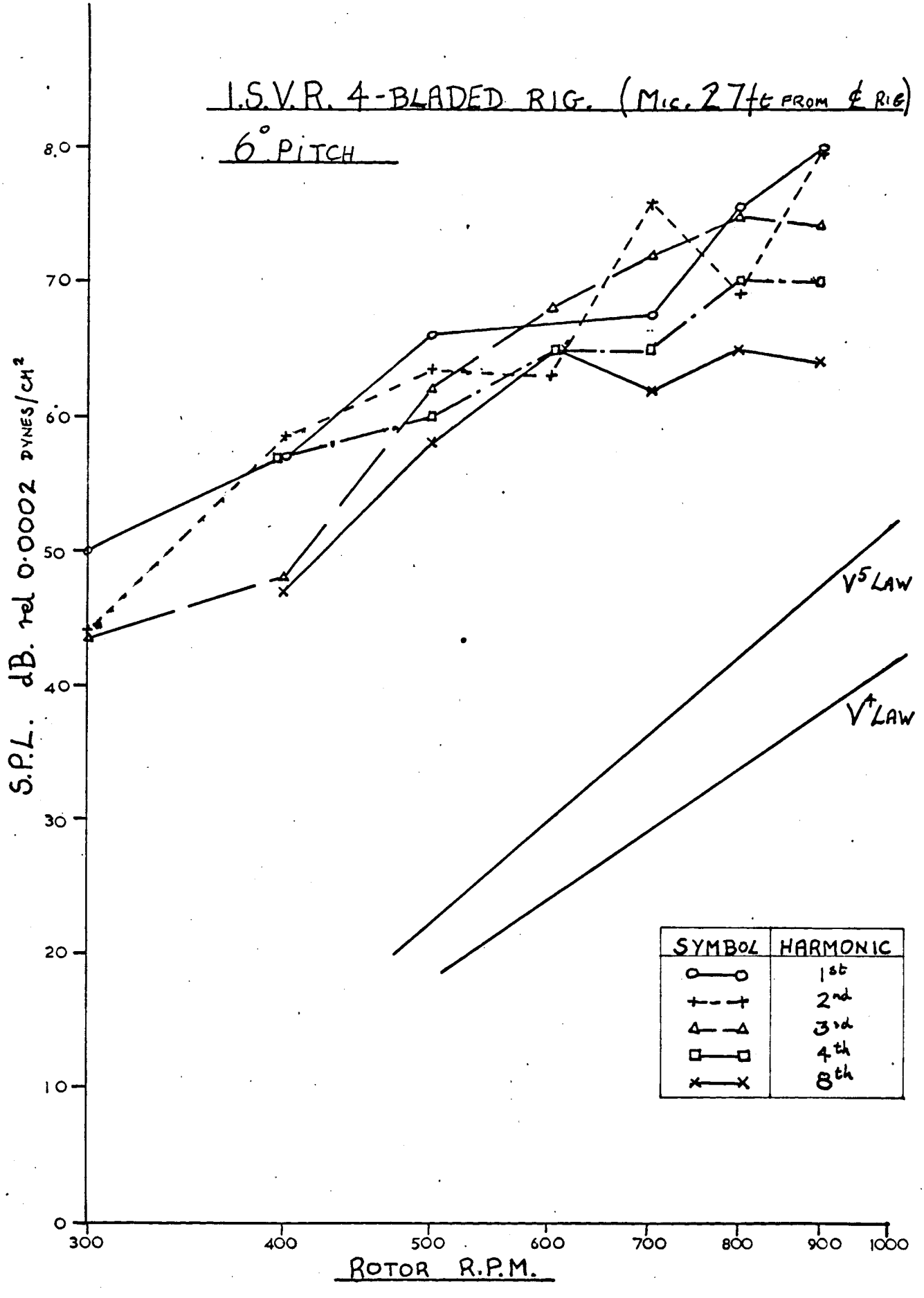
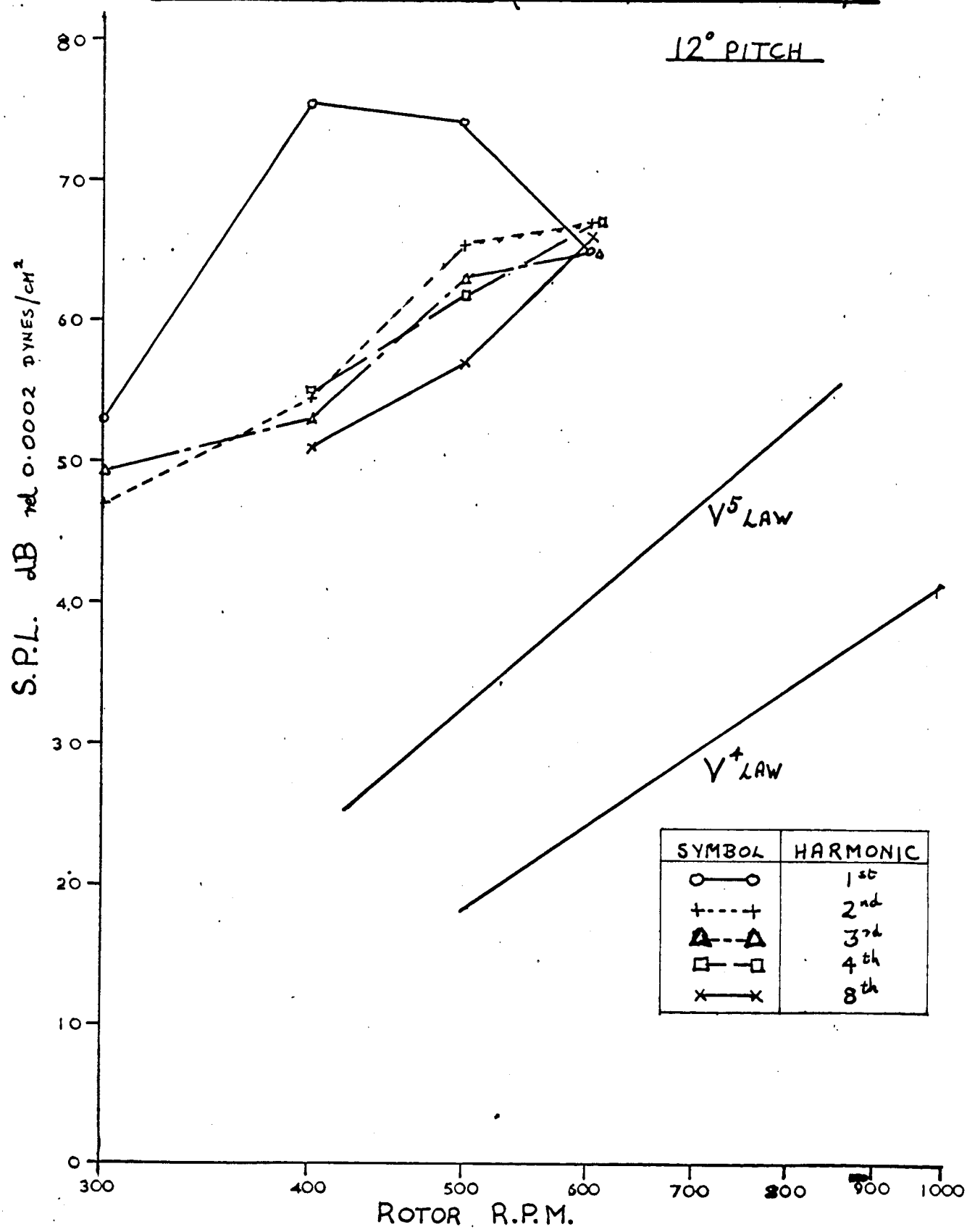


FIG 6



VARIATION OF S.P.L. WITH ROTOR R.P.M.

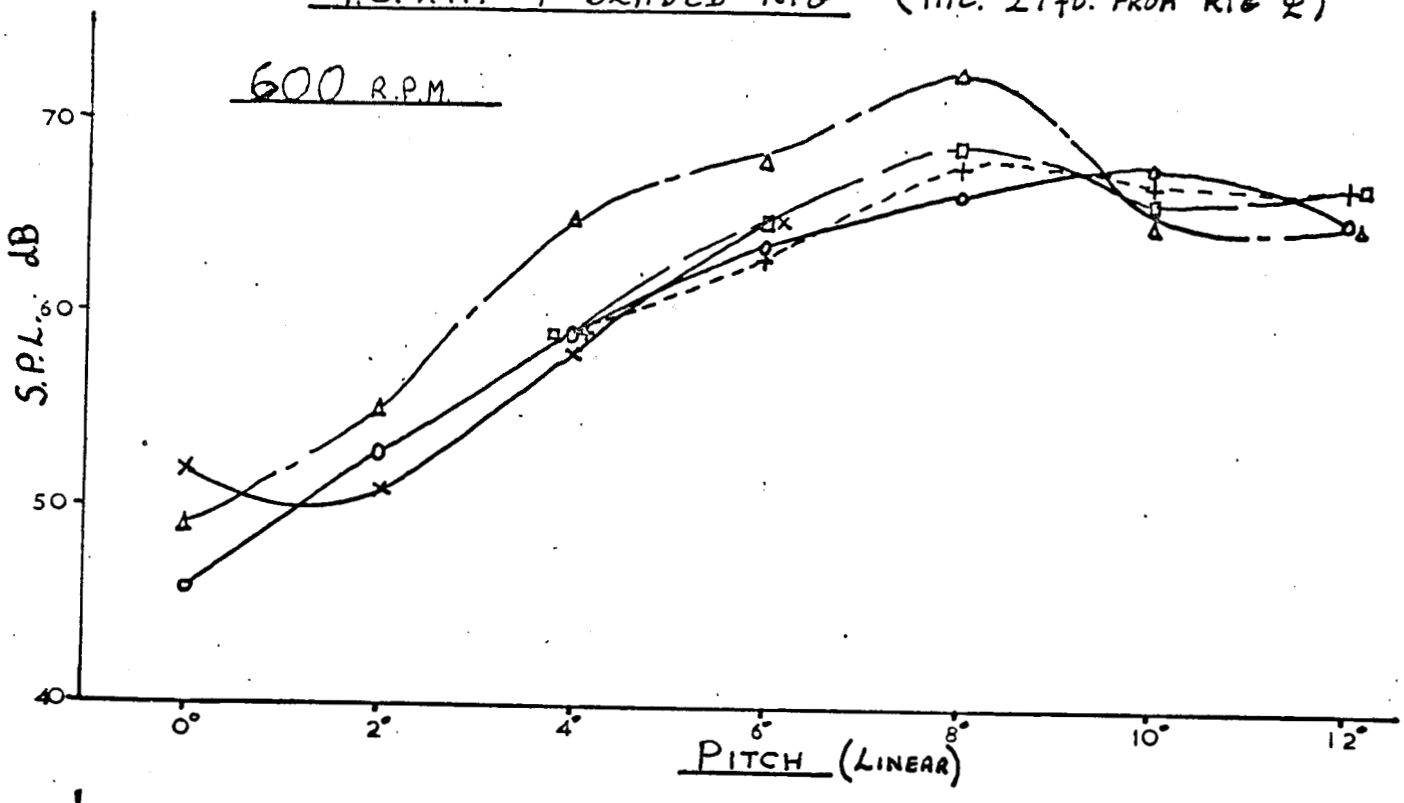
FIG 7

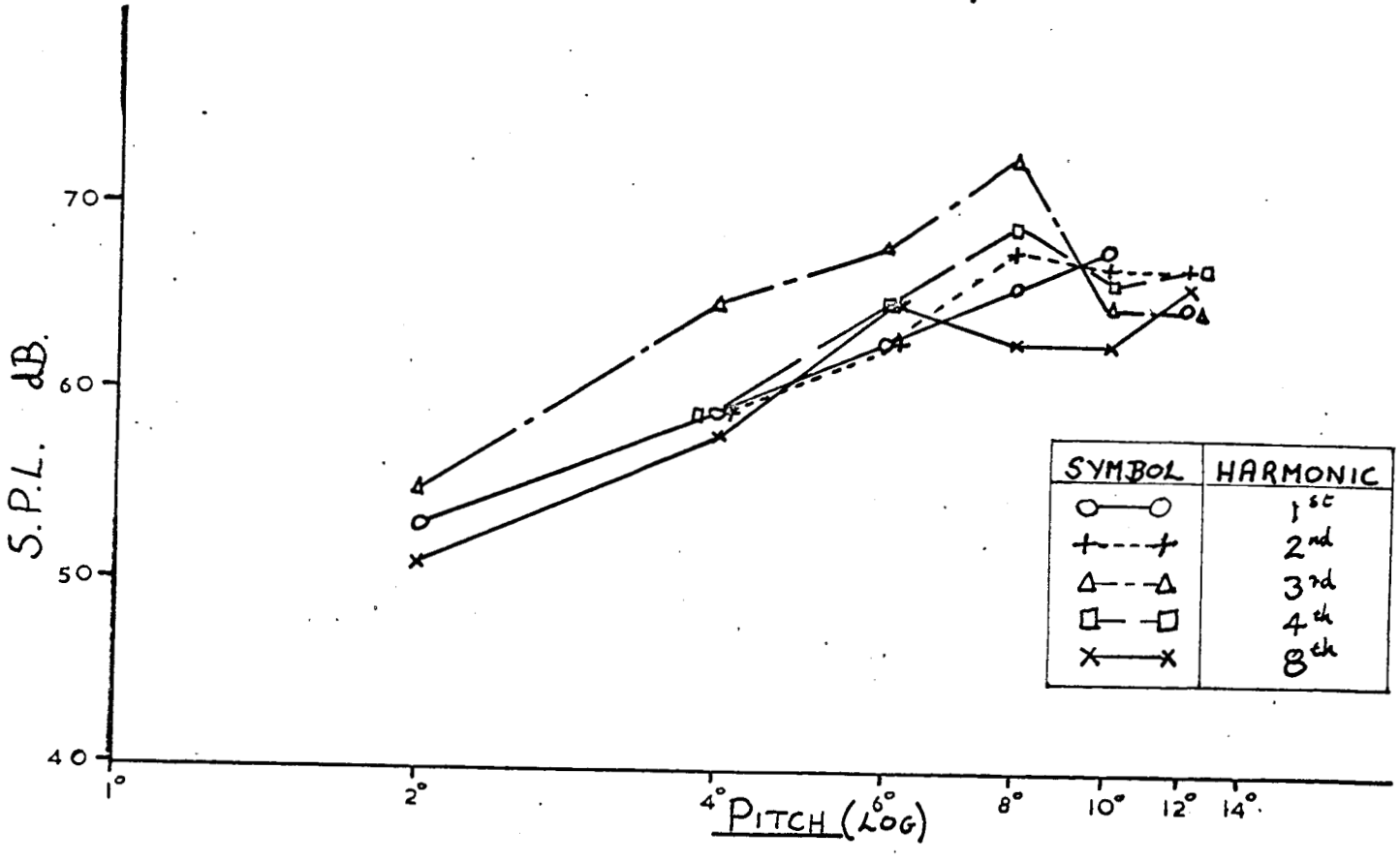


VARIATION OF S.P.L. WITH ROTOR R.P.M.

FIG 8

I.S.V.R. 4-BLADED RIG (MIC. 27ft. FROM RIG ℄)



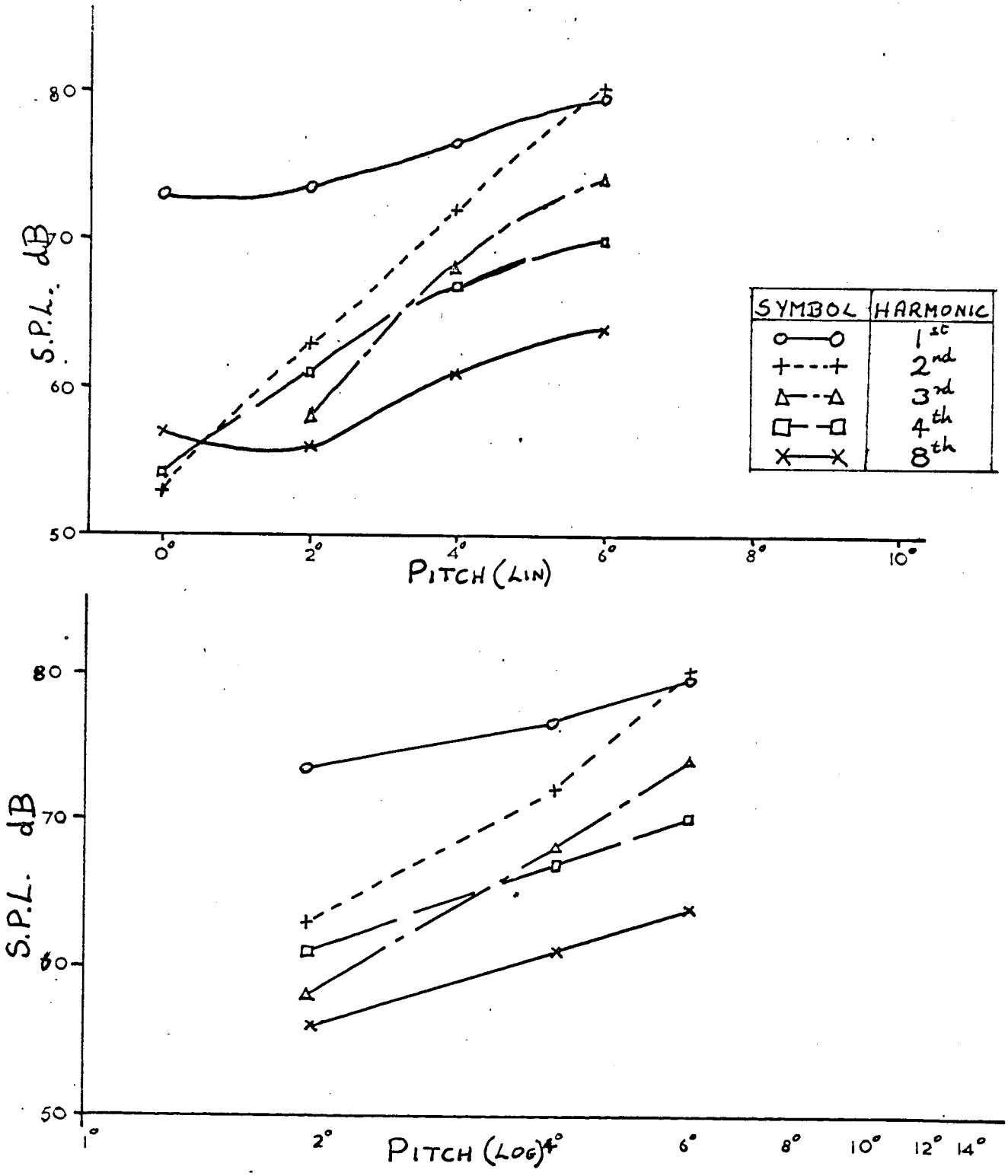


VARIATION OF S.P.L. WITH PITCH

Fig 9

I.S.V.R. 4-BLADED RIG (MIC. 27' FROM RIG ℄)

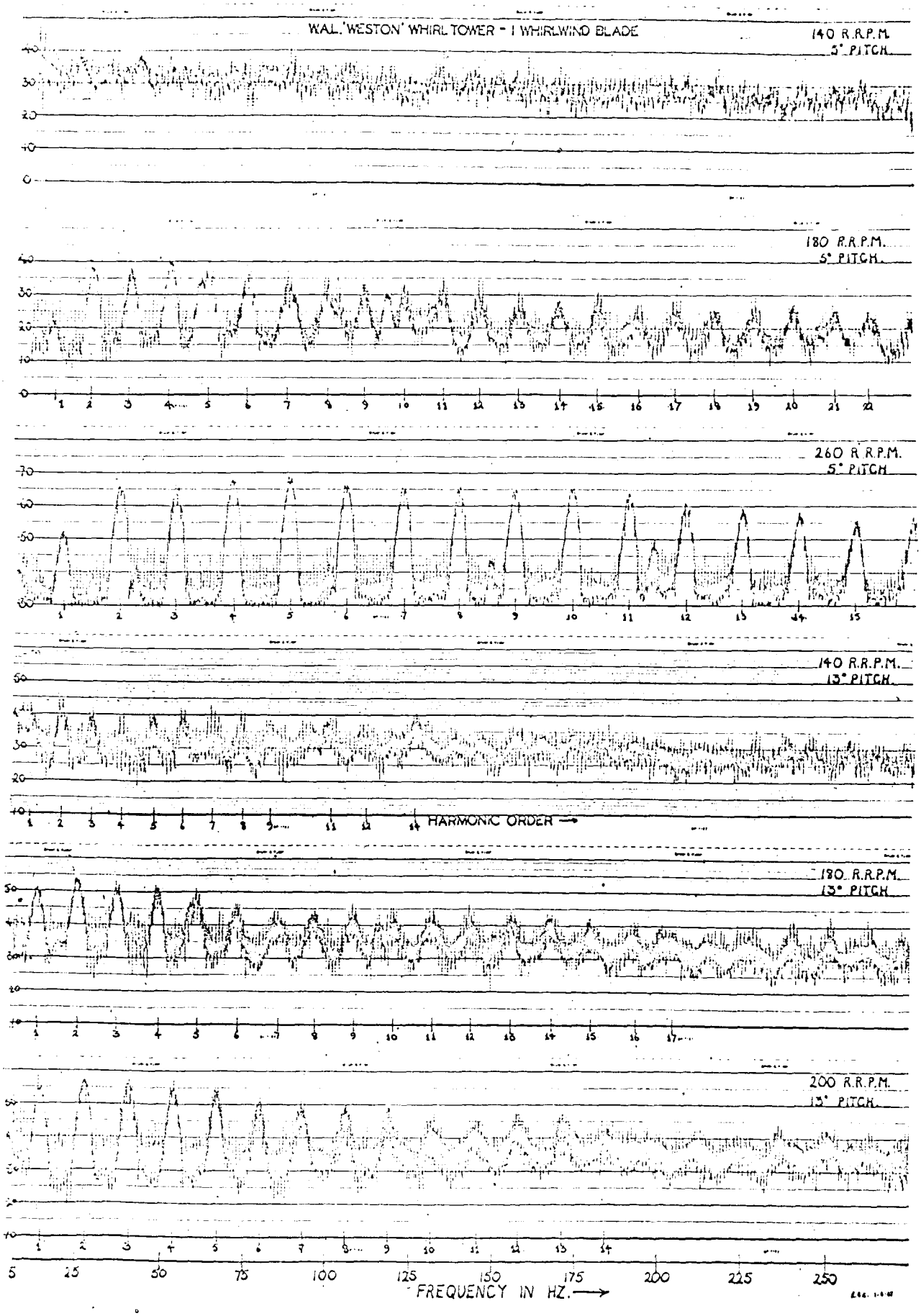
900 R.P.M.



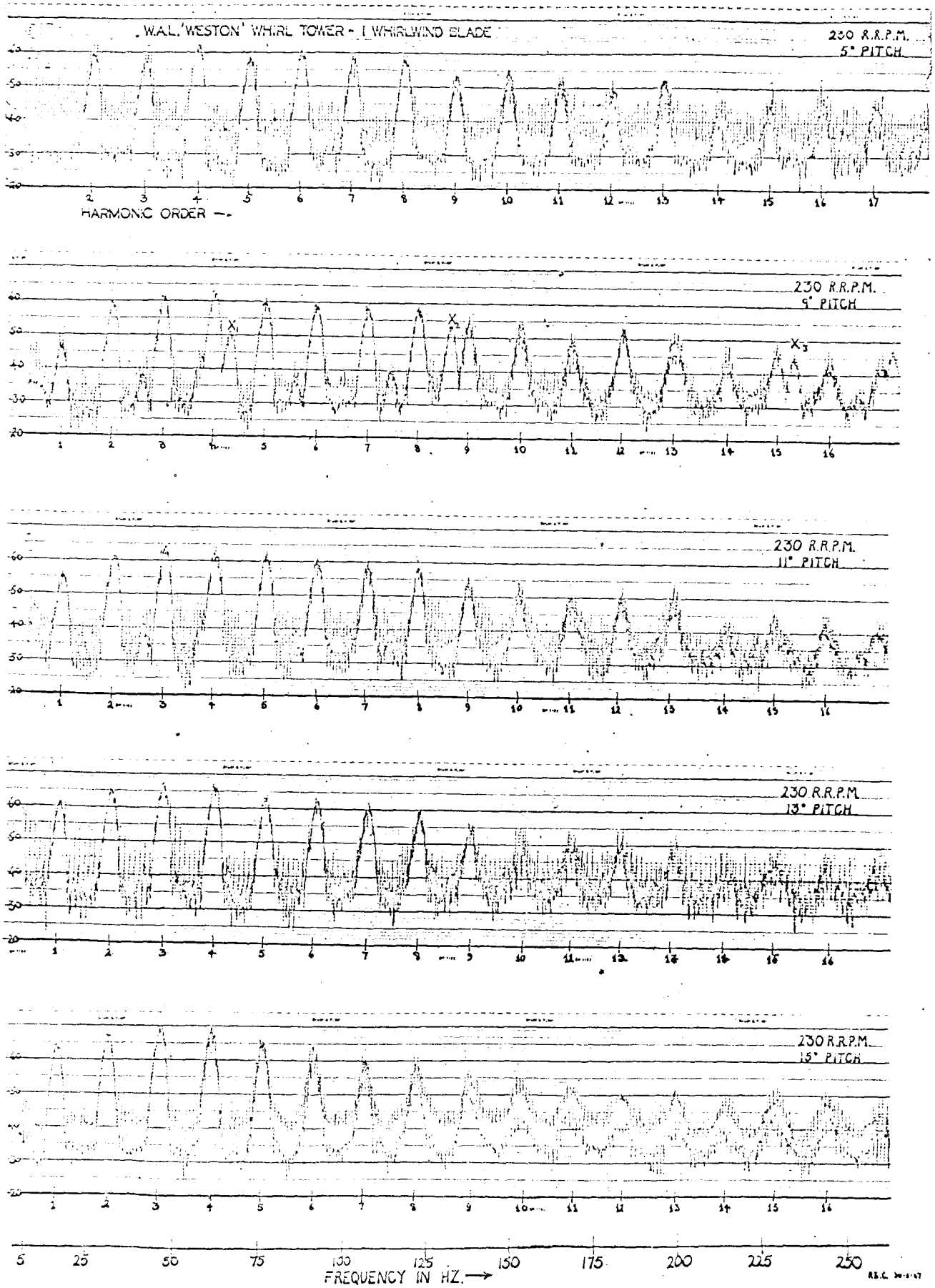
VARIATION OF S.P.L. WITH PITCH

FIG 10

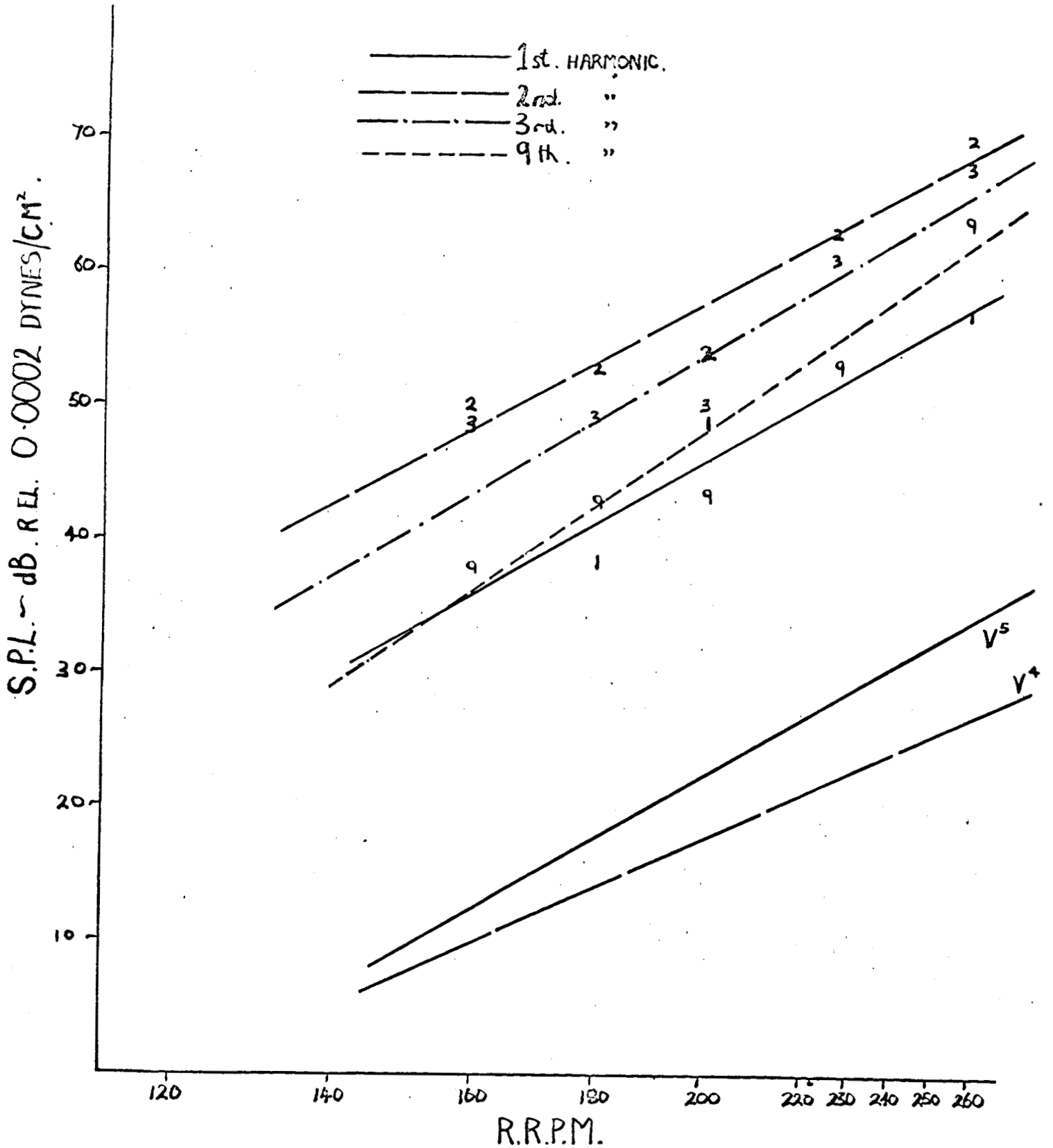
NARROW BAND ANALYSIS OF ROTOR NOISE - 2HZ. BANDWIDTH. FIG. 11.


WAL. 'WESTON' WHIRL TOWER - 1 WHIRLWIND BLADE
140 R.R.P.M. 5° PITCH
180 R.R.P.M. 5° PITCH
260 R.R.P.M. 5° PITCH
140 R.R.P.M. 13° PITCH
180 R.R.P.M. 13° PITCH
200 R.R.P.M. 13° PITCH
SPL. - dB. REL. 0.0002 DYNES/CM.²
SPL. - dB. REL. 0.0002 DYNES/CM.²
HARMONIC ORDER →
5 25 50 75 100 125 150 175 200 225 250
FREQUENCY IN HZ. →

NARROW BAND ANALYSIS OF ROTOR NOISE - 2 HZ. BANDWIDTH. FIG. 12.

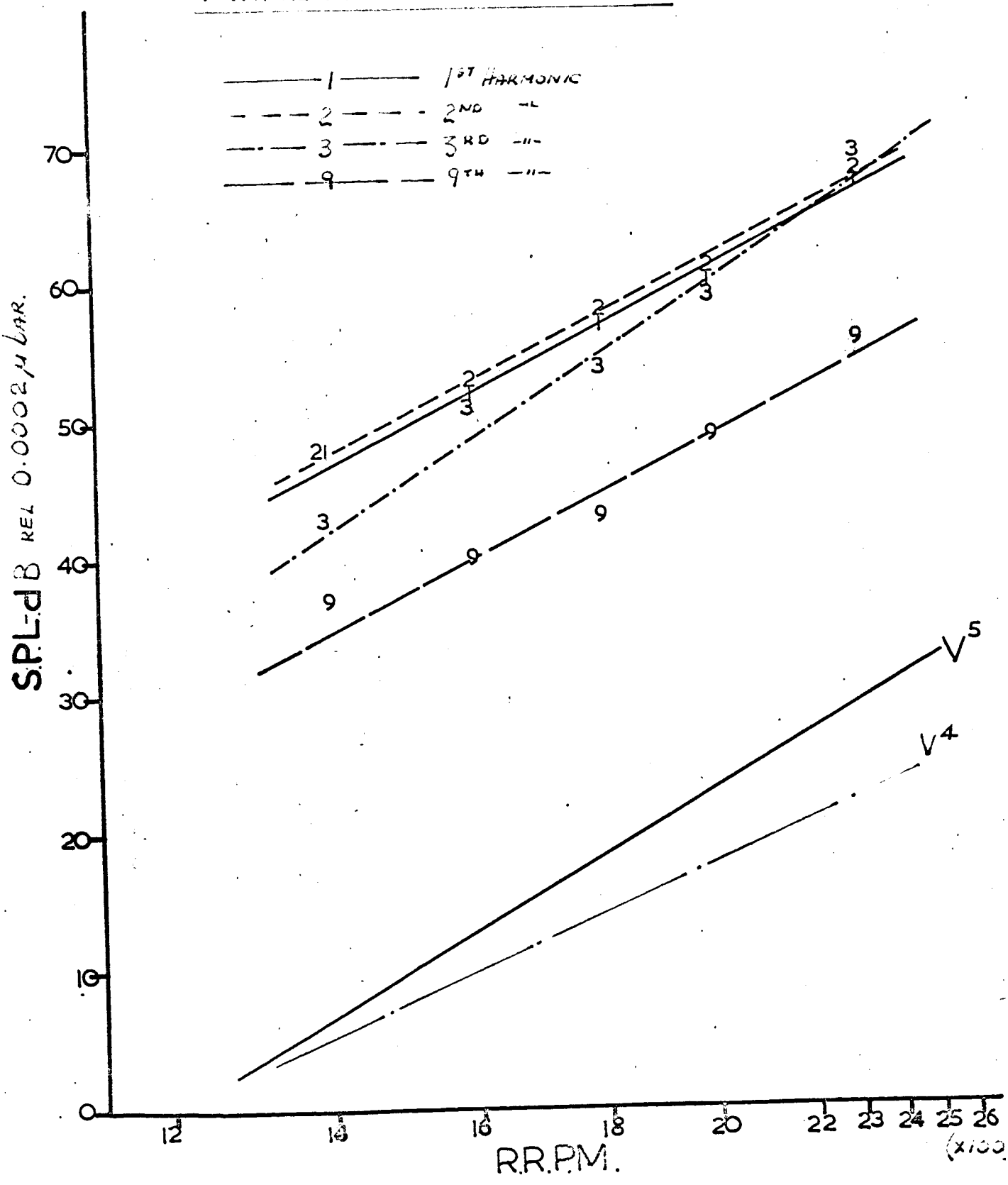


1 WHIRLWIND BLADE - 5° PITCH



VARIATION OF S.P.L WITH ROTOR SPEED AT 5° PITCH (CUFF)

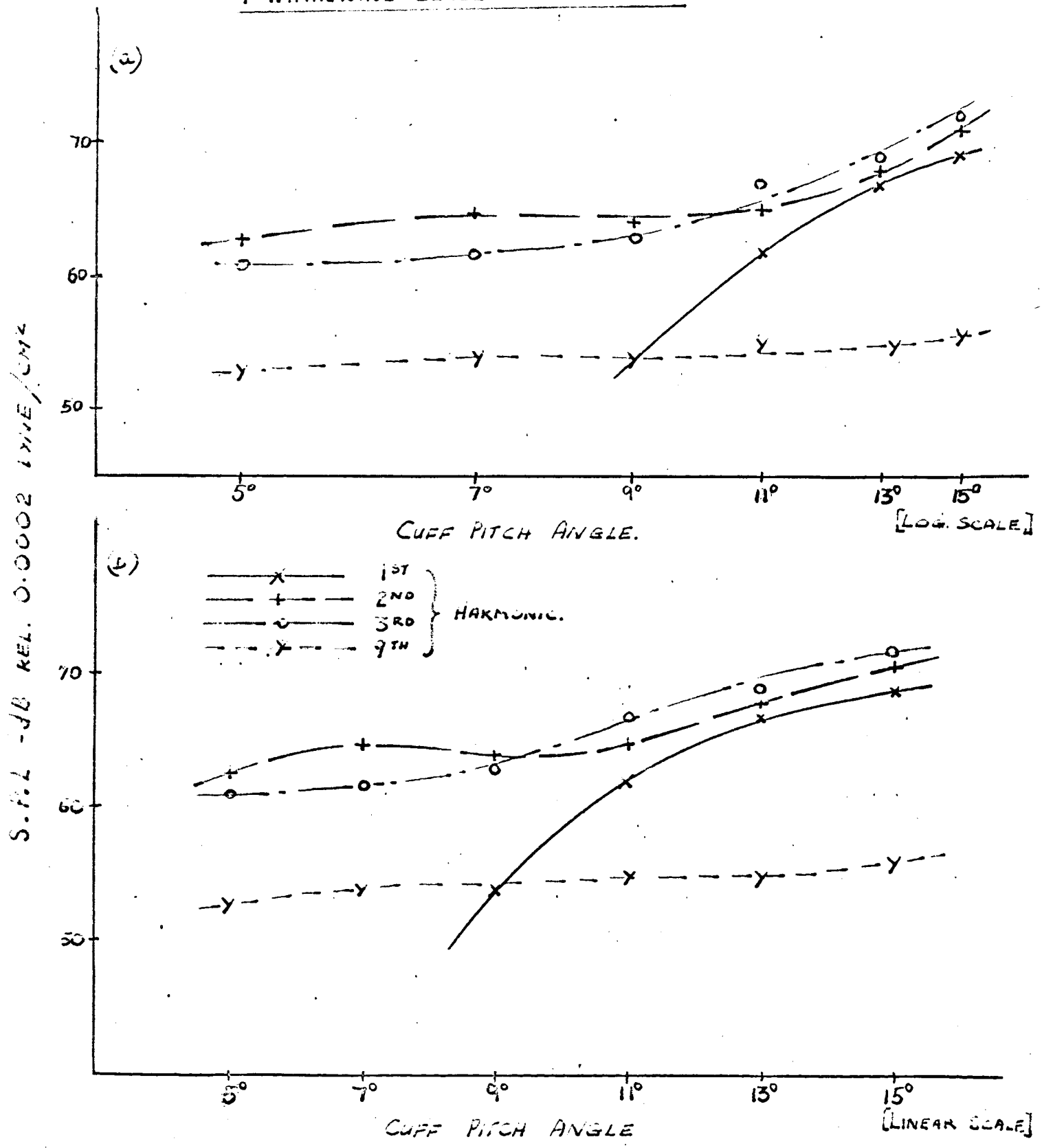
FIG 13



VARIATION OF S.P.L WITH ROTOR SPEED AT 13° PITCH (CUFF)

FIG 4.

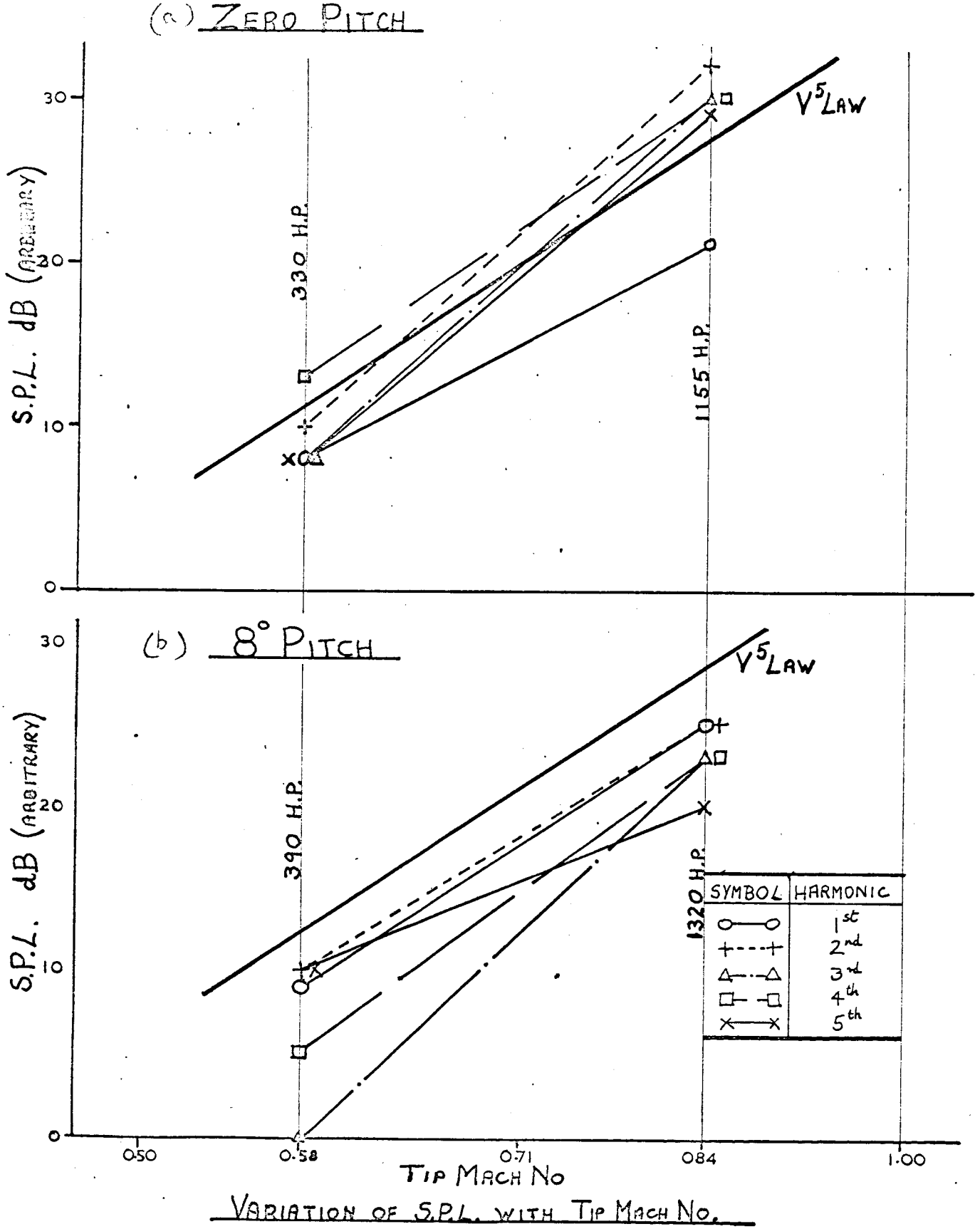
1 WHIRLWIND BLADE - 230 R.R.P.M



VARIATION OF S.P.L. WITH PITCH AT 230 R.R.P.M

FIG 15

S.R.N. 4. 19' DIAM. PROPELLER (B.H.C. RESULTS)

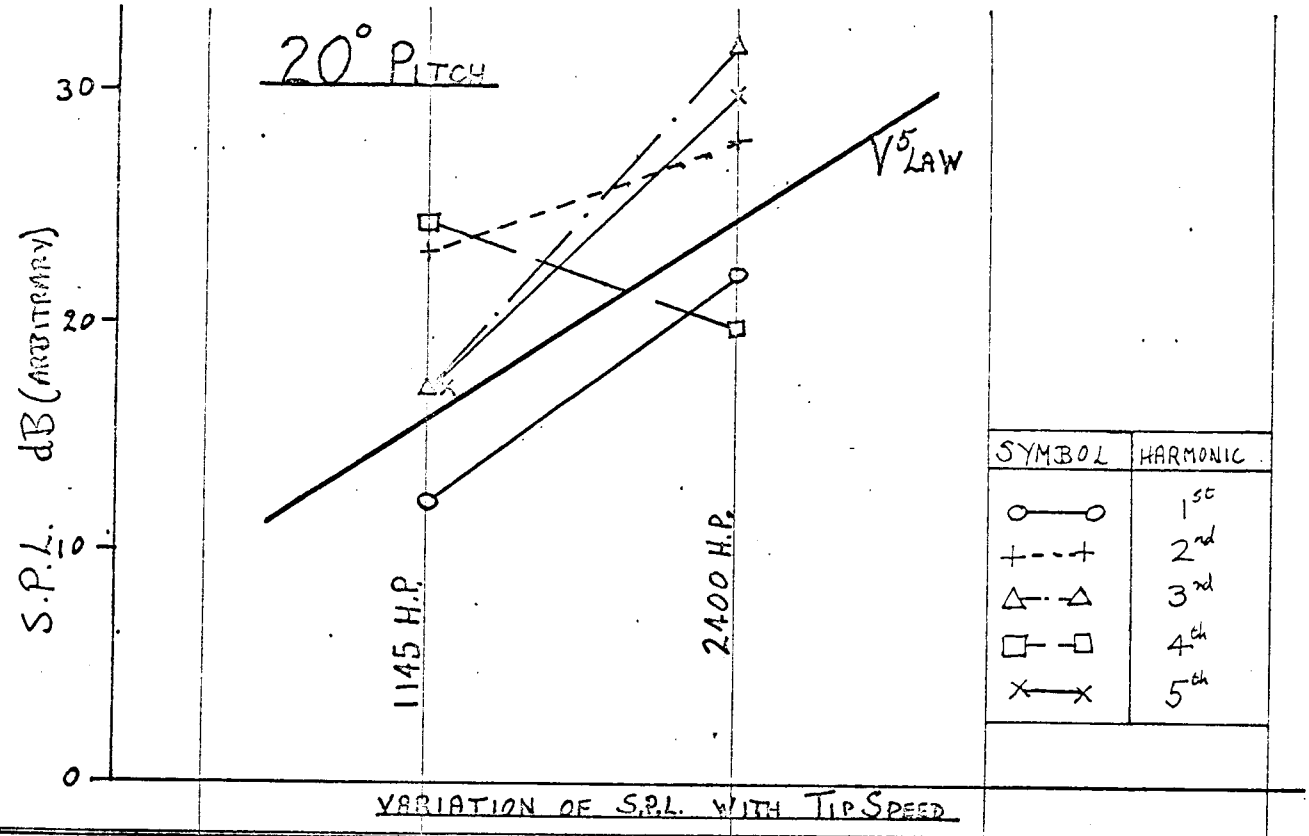


VARIATION OF S.P.L. WITH TIP MACH NO.

FIG 16

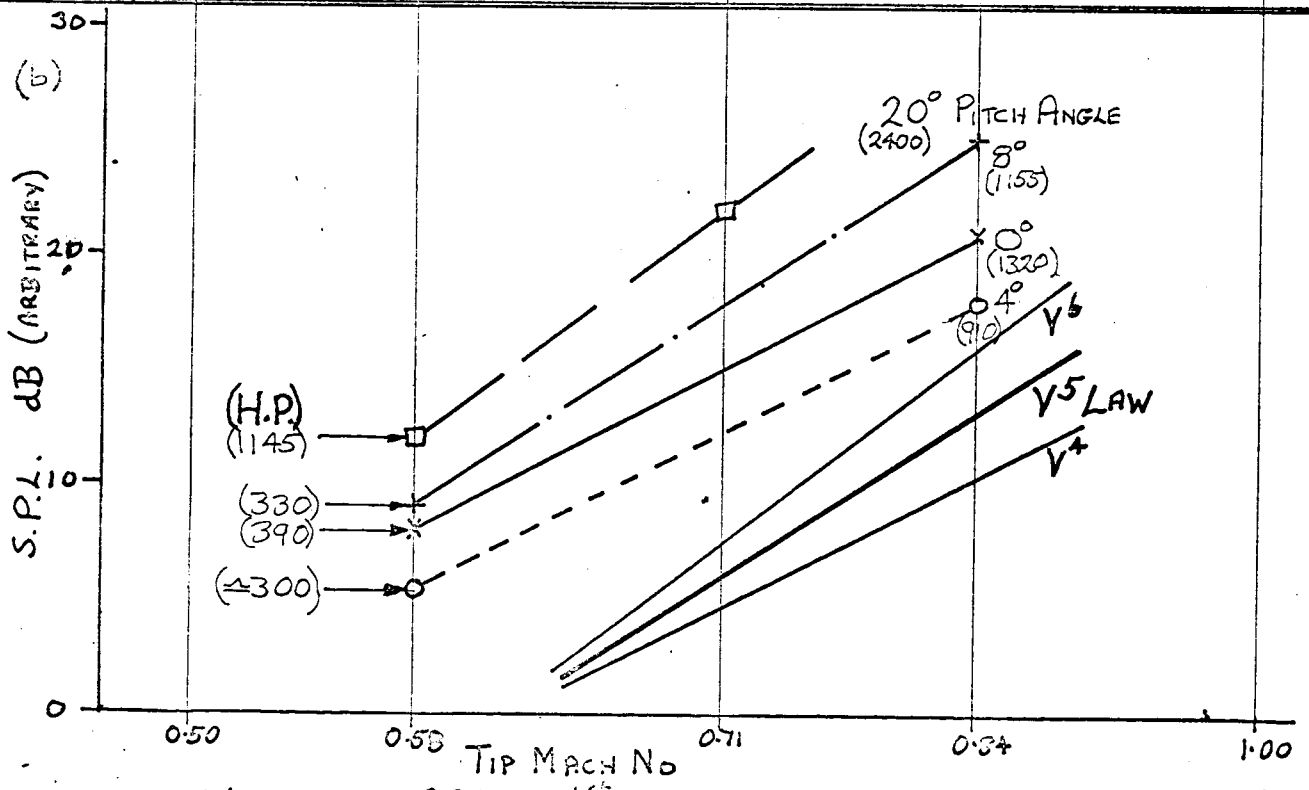
S.R.N. 4. 19' DIAM. PROPELLER (B.H.C. RESULTS)

(a)



VARIATION OF S.P.L. WITH TIP SPEED

(b)



VARIATION OF S.P.L. OF 1ST HARMONIC WITH TIP SPEED

FIG 17